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RESEARCH ARTICLE

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GPS-Based Evaluation of Activity Profiles in Elite Downhill Mountain Biking and the Influence of Course Type

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Abstract

This study aimed to profile the activity patterns of elite downhill (DH) mountain bikers during off-road descending, and to determine the influence of course types on activity patterns. Six male elite DH mountain bikers (age 20 ± 2 yrs; stature 178.8 ± 3.1 cm; body mass 75.0 ± 3.0 kg) performed single runs on one man-made (MM) and one natural terrain (NT) DH courses under race conditions. A 5 Hz global positioning systems (GPS) unit, including a 100 Hz triaxial accelerometer, was positioned in a neoprene harness between the C7 and T2 vertebrae on each rider. GPS was used to determine the temporal characteristics of each run for velocity, run time, distance, effort, heart rate (HR), rider load (RLd) which reflects instantaneous rate of change in acceleration, and accumulated rider load (RLdAcc), which reflects change in acceleration over the event duration. Significant differences were found between NT and MM courses for mean velocity ($p<.001$), peak velocity ($p=.014$), mean RLd ($p=.001$) and peak RLd ($p=.002$). Significant differences were also found both within and between courses for all velocity parameters, when analysed by intensity zone ($p<.05$). No significant differences were found between courses for HR parameters by zone, though significant differences were revealed between HR zones within courses ($p<.05$). This study indicates that course terrain has a significant impact on the activity profiles of DH and that GPS can provide a practical means of monitoring these differences in activity.

Keywords: cycling, intensity, motion analysis, performance

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Introduction

Downhill (DH) mountain biking is a demanding outdoor sport, with elite level races lasting between 2 and 5 min and course lengths ranging from 1.5 to 3.5 km (Union Cycliste Internationale 2012). Unlike other mountain bike disciplines, such as cross-country, the focus of DH racing is more on the technical ability of the rider than aerobic fitness (Hurst and Atkins 2006).

Downhill events use either natural terrain (NT) or man-made (MM) courses. Natural terrain courses predominately use the existing topography of the landscape to mark out a course down the hillside and are typical of World Cup event courses. In contrast, MM courses are sculpted using diggers and tend to have smoother, more flowing riding surfaces that include large purpose-built jumps and smooth banked corners and are more typical of purpose-built mountain bike parks, though these parks often hold elite level, non-World Cup DH events. Due to the differing nature of NT and MM courses the activity profiles during DH may also differ. As elite DH riders frequently train and compete on different course types, a comparison of the activity profiles between NT and MM courses is justified.

Despite DH's popularity, little is known about the activity profiles of the sport. Studies that have investigated the responses to DH have used heart rate (HR) monitoring, power output and gas analyses to determine the intensity profile of DH riding (Hurst and Atkins 2006; Burr et al. 2012; Sperlich et al. 2012). However, these studies do not present the temporal changes in these measures of exercise intensity. In addition, HR's during DH have been shown to be very stable (Hurst and Atkins 2006; Burr et al. 2012; Sperlich et al. 2012), despite Hurst and Atkins (2006) proposing that DH is intermittent in nature. Therefore, the use of an alternative method to determine the activity profiles of DH riding is warranted.

Time motion analysis (TMA) has been used extensively to monitor activity in field-based team sports (Spencer et al. 2004; Duthie et al. 2005; Roberts et al. 2006; Deutsch et al. 2007). However, in cycling its use is limited. Cowell et al. (2011) conducted a

TMA of temporal patterns in elite Supercross BMX using video analysis. Though video analysis provides a valid means of quantifying activity profiles (Deutsch et al. 2007), it is time consuming (Roberts et al. 2006). Further, these methods require a clear view of the sporting area, making their use impractical for sports such as mountain biking.

Global positioning systems (GPS) provide advantages over previous TMA methods, as they allow quick and accurate analysis of activity profiles in real-time and are not limited by the necessity of a clear view of the sporting area (Aughey 2011). The validity and reliability of GPS for the assessment of activity profiles in outdoor activities have been well documented (Witte and Wilson 2004; Edgecomb and Norton 2006; MacLeod et al. 2008; Cunliffe et al. 2009; Coutts and Duffield 2010; Gabbett 2010; Portas et al. 2010; Wisbey et al. 2010; Petersen et al. 2011). Newer GPS units also include triaxial accelerometers and gyroscopes. These sensors monitor the magnitude of movement in three cardinal planes (Krasnoff et al. 2008; Boyd et al. 2011), to determine measures of athlete exertion, which are not dependent on distance. Boyd et al. (2011) validated the use of accelerometers for measuring physical activity, and reported coefficient of variations of <2 % for both static and dynamic measures of activity. Such measures of exertion may be more ecologically valid for sports such as DH, as course terrain and bicycle set up are likely to influence the magnitude of forces and changes in accelerations encountered by the rider.

The potential benefits of using GPS technology to monitor activity profiles in DH are many. Data collected from GPS may be used to track and plan athletes' training loads throughout the season and monitor race performance. In addition, such data may also inform riders and mechanics on how best to set up bicycles for each race course. Therefore, the aims of this study were to quantify the activity profiles of elite DH mountain bikers during off-road descending using GPS and accelerometry, and to determine the influence of course type on activity profiles.

Materials and methods

Participants

This study was pre-approved by the Regional Ethical Review Board of Umeå University and the University of Central Lancashire Ethics Committees, and was in accordance with the Declaration of Helsinki and the international standards required by the Journal of Science and Cycling (Harriss and Atkinson 2011). Verbal and written informed consent was obtained from all participants prior to the study. Six male elite DH mountain bikers (age 20 ± 2 yrs; stature 178.8 ± 3.1 cm; body mass 75.0 ± 3.0 kg) representing the Swedish National DH Cycling team took part in this study.

Course Profile and Instrumentation

Testing was conducted at the Åre Bike Park, Åre, Sweden. Riders were required to perform runs on two technically different courses. These were classified as NT (length = 1363 m, vertical drop = 431 m, mean gradient = 29.2 %) and MM (length = 2182 m, vertical drop = 473 m, mean gradient = 22.9 %). Courses were typical of the type of terrain encountered at elite DH events. Both courses were a mix of open tracks and forest sections. A GPS trace of the NT and MM courses is presented in Figure 1. Course profiles were recorded using a 5 Hz GPS (Minimax X3, Catapult Innovations, Melbourne, Australia) positioned in a harness between the C7 and T2 vertebrae. The validity and reliability of the Minimax X3 has previously been reported by Janssen and Sachlikidis (2010). Heart rates were recorded using a wireless coded transmitter belt (Wearlink, Polar, Finland), positioned at the xiphisternal junction, and the GPS's built in receiver. Heart rate was sampled at 1 s intervals. To remove the possibility of inter-unit variability, the same GPS unit was used for all riders and course runs. GPS data were used to determine mean run time (s), mean and peak velocity (km.h^{-1}), percentage time spent in velocity zones (0-10, 10-20, 20-30, 30-40, 40-50, and 50-60 km.h-1, respectively), the number of 'efforts' per velocity zone and mean distance of efforts in each velocity zone. In order for the GPS unit to register an 'effort', velocity or HR had to increase or decrease by at least two zones. This process helps to avoid multiple efforts being counted when parameters are fluctuating around a zone boundary (Catapult Innovations, Melbourne, Australia 2011). Overall mean and peak HR, percentage time spent in HR zones (<100, 100-125, 125-150, 150-175, 175-200 and >200

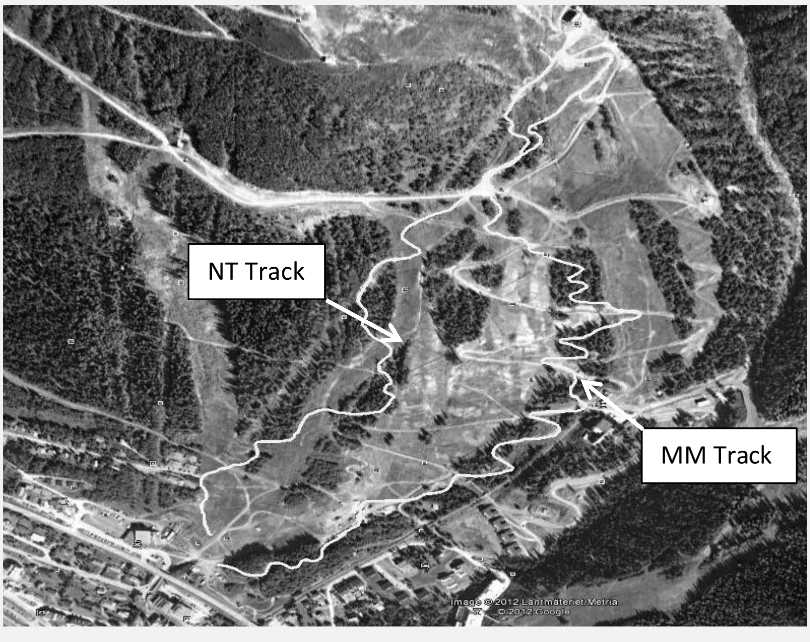

Figure 1. GPS plot of NT and MM tracks overlaid into Google Earth.

beats.min-1, respectively), and percentage run time spent above 90 % peak HR were also determined.
Heart rate zones were determined using the default zones set in the GPS's proprietary software (Logan Plus V4.6.1, Catapult Innovations, Melbourne, Australia). These zones were comparable to the exercise intensity zones proposed by Pollack and Wilmore (1990). The Minimax X3 GPS also comprised a triaxial accelerometer (Catapult Innovations, Melbourne, Australia), sampling at a rate of 100 Hz. Boyd et al. (2011) had previously validated the reliability and accuracy of the Minimax X3 accelerometer. The accelerometer was used to determine mean and peak instantaneous rider load (RLd), which reflects the instantaneous rate of change in acceleration, and accumulated rider load (RLdAcc), reflecting the rate of change in acceleration over the event duration, for each course. Riders were allowed two days to familiarise themselves with the courses prior to data collection, and were allowed to use their own race bikes throughout the study. All riders used full suspension DH mountain bikes with 202 ± 1.55 mm of suspension in the travel front and rear.

Test Protocols

A 10 min self-paced warm up on a SRM cycle trainer, which included a series of maximal effort sprints, was followed by dynamic stretching. Riders then made their way to the start of the courses via chair-lift. Prior to testing, the GPS was activated and left for 10 min. This allowed the unit to download ephemeris data from the satellites used to calculate location and distance. Riders were instructed to cycle or walk around the start area to keep warm during this time. Riders were then given a 10 s warning, followed by the command '3, 2, 1, GO'. Riders each performed one run of the NT and MM courses with a 15 min rest period between runs. Run order was randomised for all participants. Upon completion of each run data were downloaded from the GPS to a laptop computer for later analyses.

Statistical analyses

Differences in activity profile measures between courses were determined using paired samples t-tests. Within course differences for velocity and HR zone data were determined using one-way analysis of variance (ANOVA). In the instance of any significant interaction effects, Bonferroni corrections were used during post hoc comparisons to control for type I errors. If the homogeneity assumption was violated then the degrees of freedom were adjusted using the Greenhouse Geisser correction. Effect sizes were calculated using a partial Eta2 (η2). Based on Cohen's d (Cohen 1988), effect size values of >0.8 were considered large, ~0.5 as moderate and <0.2 as small. Significance was accepted at the $p \leq .05$ level and data presented as means ± standard deviations (SD). All statistical procedures were conducted using SPSS 20.0 (SPSS Inc., Chicago, IL, USA).

Results

Overall activity profile measures for each course are presented in Table 1. When percentage run time was analysed by velocity zones, significant differences were revealed between courses. Figure 2 presents the mean percentage run time spent in each velocity zone by course. For the NT course the majority of run time was spent in the 20-30 km.h-1 zone (43.3 ± 3.7 %), whilst for the MM course the majority of time was spent in the 30-40 km.h-1 zone (39.5 ± 2.6 %). Significant differences between courses regarding the number of efforts performed in each velocity zone were also identified. These differences are presented in Figure 3. The mean distance travelled per effort also differed

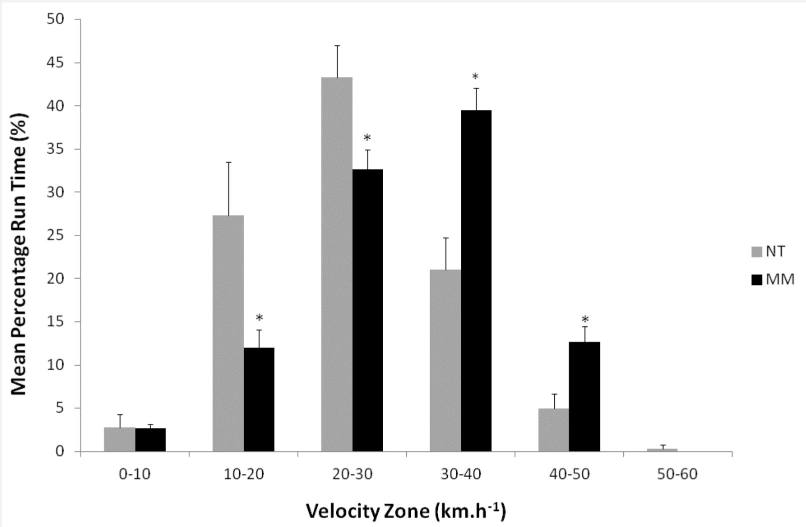

Figure 2. Percentage run time spent in each velocity zone by course. * Significantly different to NT course. NT = Natural terrain; MM = Man-made terrain.

Table 1. Overall activity profile parameters recorded during NT and MM courses.

Variable	NT	Range	MM	Range
Run Time (s)	191.7 ± 8.5	179 - 201	252.7 ± 6.1*	243 - 259
Mean Velocity ($km.h^{-1}$)	24.9 ± 1.5	22.6 - 26.9	29.6 ± 0.4*	28.9 - 30.2
Peak Velocity ($km.h^{-1}$)	52.7 ± 2.3	48.4 - 54.5	49.1 ± 1.3*	47.4 - 51.1
Mean RLd (a.u.)	1.7 ± 0.3	1.2 - 2.0	1 .3 ± 0.2*	1.0 - 1.6
Peak RLd (a.u.)	4.8 ± 0.8	3.6 - 5.9	3.6 ± 0.4*	3.0 - 4.0
RLd_{Acc} (a.u.)	83.8 ± 14.7	59.0 - 102	81.0 ± 13.0	62.0 - 102
Mean HR ($beats.min^{-1}$)	177 ± 10	163 - 188	177 ± 9	164 - 190
Peak HR ($beats.min^{-1}$)	189 ± 13	170 - 206	190 ± 12	175 - 205

All results are presented as mean ± SD. * significantly different from NT course. NT= Natural terrain; MM = Man-made terrain; RLd = Rider load; RLdAcc = Rider load accumulated; HR = Heart rate.

significantly between courses based on velocity zone. Figure 4 presents the mean distance travelled per effort by velocity zone for each course.

Analysis of the percentage run time spent in each velocity zone also found significant differences within the NT course ($p<.001$ $\eta^2 = .96$). Post hoc pairwise comparisons revealed significant differences between all velocity zones except the 0-10 and 40-50 km.h-1, 0-10 and 50-60 km.h-1, and 40-50 and 50-60 km.h-1 zones. Significant differences were also found for the number of efforts performed per velocity zone for the NT course ($p<.001$, $\eta^2 = .90$). Post hoc comparisons revealed significant differences between all velocity zones with the exceptions of the 0-10 and 50-60 km.h-1, and 10-20 and 40-50 km.h-1 zones. In addition, significant differences were found for the mean distance ridden per effort in each velocity zone within the NT course ($p<.001$, $\eta^2 = .87$). Post hoc comparisons showed significant differences between the 0-10 and 10-20, 0-10 and 20-30, 10-20 and 20-30, 10-20 and 50-60, 20-30 and 30-40, 20-30 and 40-50 and 20-30 and 50-60 km.h-1 zones.

Percentage of run time spent in each velocity zone within MM course runs, were significantly different ($p<.001$, $\eta^2 = .99$). Post hoc analyses revealed these significant differences occurred between all velocity zones except the 0-10 and 50-60 km.h-1 and 10-20 and 40-50 km.h-1 zones. Significant differences were found for the number of efforts performed per velocity zone for the MM course ($p<.001$, $\eta^2 = .96$). Post hoc analyses found the significant differences occurred between all zones with the exception of the 10-20 and 20-30 km.h-1 zones. Again, significant differences were also found for the mean distance ridden per effort in each velocity zone within the MM course ($p<.001$, $\eta^2 = .95$). Post hoc analyses showed differences between all velocity zones except the 30-40 and 40-50 km.h-1 zones.

Analysis of HR data revealed no significant differences between NT and MM courses by HR zones. Mean percentage run time, per HR zone, is presented in Figure 5 for each course. Mean HR was >93 % of peak HR

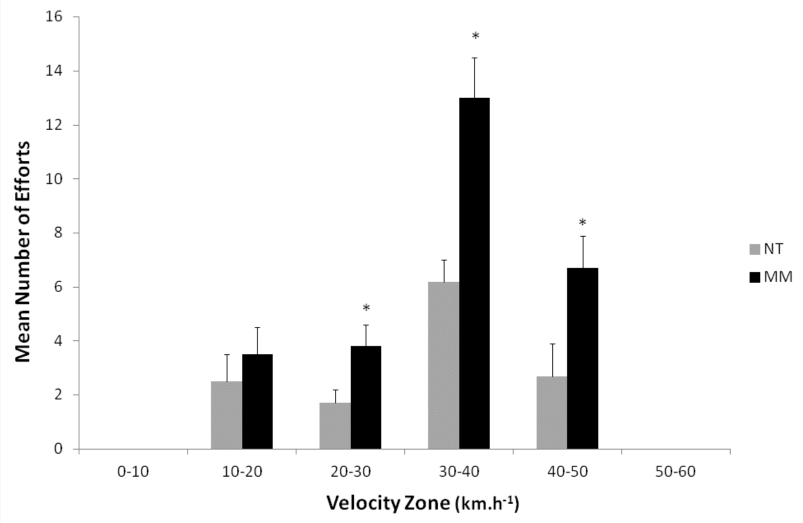

Figure 3. Mean number of efforts performed per velocity zone by course. * Significantly different to NT course. NT = Natural terrain; MM = Man-made terrain.

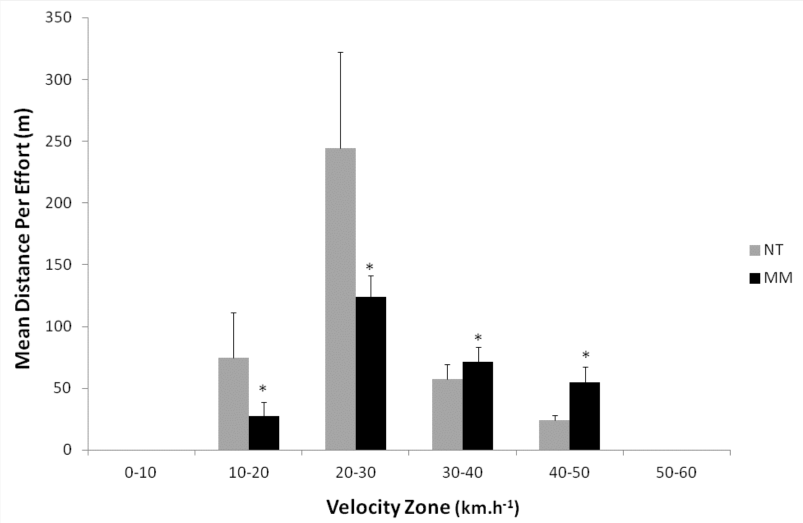

Figure 4. Mean distance travelled per effort in each velocity zone by course. * Significantly different to NT course. NT = Natural terrain; MM = Man-made terrain.

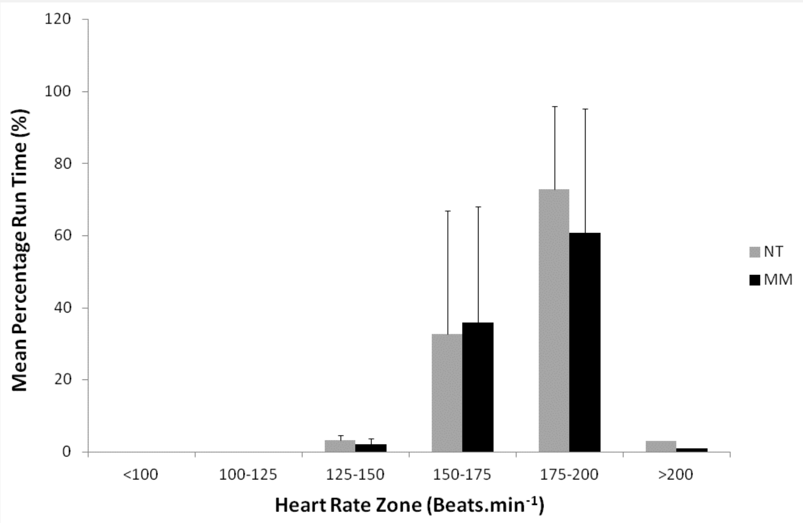

Figure 4. Mean percentage run time spent in each heart rate zone by course. NT = Natural terrain; MM = Man-made terrain. Note: No significant differences were identified between courses.

recorded during both NT and MM runs, When HR was analysed by HR zones, a mean of 73 % of NT course run time was spent between 175 and 200 beats.min-1, corresponding to >90 % of peak HR. For the MM course, the time spent above 90 % of peak HR was 61 %.

The percentage run time spent within different HR zones was also found to be significantly different within the NT course ($p<.001$, $\eta2 = .70$). Post hoc analyses revealed significant differences between the 100-125 and 175-200, 125-150 and 175-200, and 150-175 and 175-200 beats.min-1 zones. Additionally, significant differences were also revealed for the mean HR's reported within each HR zone for the NT course ($p<.001$, $\eta2 = .99$). Post hoc analyses found significant differences in mean HR existed between all HR zones.

Percentage run time spent in each HR zone was also found to be significantly different within the MM course ($p=.001$, $\eta2 = .58$). Post hoc analyses found significant differences between the 100-125 and 175-200 beats.min-1 and the 125-150 and 175-200 beats.min-1 zones. Significant differences were again revealed for the mean HR's within each HR zone for the MM course ($p<.001$, $\eta2 = .89$). Post hoc analyses found significant differences existed between the 100-125 and 125-150, 100-125 and 150-175, 100-125 and 175-200 and 100-125 and >200 beats.min^{-1} zones.

Discussion

This study aimed to identify the activity profiles of elite DH mountain bikers using GPS technology and accelerometry. A secondary aim was to evaluate the influence of different course types on these activity profiles. The main findings of the present study showed that mean and peak velocity and RLd were significantly influenced by course type. This suggests that GPS may be sensitive enough to detect the influence of course terrain when monitoring DH training and performance.

The use of GPS to identify differences in activity profiles on different courses, and to pinpoint rider responses at any given point, presents a considerable advantage over previously utilised methods of profiling for DH performance. Methods such as HR monitoring have been shown to be influenced by factors including isometric muscle contractions, environmental conditions and body position (Gnehm et al. 1997; Smolander et al. 1998; Stannard and Thompson 1998). However, modern GPS units allow riders and coaches to not only monitor HR, but also changes in velocity, the number of efforts throughout the course, and other metrics for exercise intensity, such as the loads exerted upon a rider. These may provide more ecologically valid means of determining activity patterns and intensity levels in DH mountain biking.

Mean velocity for the MM course was significantly greater than that recorded for the NT course. This was most likely due to the smoother, more flowing nature of this course type. Riders potentially braked less frequently on the MM course and therefore carried speed through corners more effectively, thereby maintaining velocity. In contrast, the NT course required riders to negotiate numerous rocks, tree roots and tighter radii corners that were not encountered on the MM course, ultimately leading to the lower mean velocity observed during NT runs.

It could be argued that the NT course was more technical in nature than the MM course, due to the more direct route down the mountain and the rougher terrain encountered. As a result opportunities to pedal may have been limited. Despite this, peak velocity was significantly higher for the NT course. Reviews of the GPS data revealed that all riders achieved peak velocity within the same 100 m stretch of the NT course, which at a descent angle of ~49°, was steeper than similar length straight sections of the MM course. Post-run analyses showed that the time spent in different velocity zones also differed significantly both between and within the courses. Within the NT course the majority of run time was spent between 20-30 km.h^{-1}, whilst during the MM course the greatest percentage of run time was performed between 30-40 km.h^{-1}. However, the MM course was generally less steep and probably resulted in the lower mean peak velocity observed, demonstrating the influence that course type plays on the activity profile of DH riding.

The GPS unit used in the current study had the ability to determine the number of efforts performed within a particular velocity or HR zone and also determine the mean distance of all efforts with a velocity zone. This may provide a more informative index of how hard and frequently the riders were working than the use of HR monitoring. Unlike the differences in run time spent in each velocity zone between courses, when the number of efforts per zone were analysed within courses, riders performed the majority of efforts between the 30-40 km.h^{-1} zone for both courses. A between-course analysis revealed significantly more efforts were performed within this zone during the MM runs. The number of efforts performed is again likely to be dictated by course terrain, and the higher number of efforts in each velocity zone during the MM course most likely reflects the greater opportunities for pedalling. Interestingly, the results also show that the mean distance covered per effort was significantly greater at lower velocities during NT runs. This would suggest that though pedalling opportunities may be limited due to course terrain during these runs, riders sustained efforts for further, potentially to limit reductions in velocity. In all cases, it should be noted that high SD values were present for velocity parameters, indicating potential variability in rider effort, skill levels or riding style. The analysis of the number of efforts performed at different velocities may provide riders and coaches information on where time can potentially be gained or lost, and can help track development on specific courses either other a season or over a race weekend.

Instantaneous RLd was also reported as it provides a measure of exertion that is not based on distance alone. As it is determined from the instantaneous rate of change in acceleration in the x, y and z axes, this provided a useful tool for monitoring activity in DH.

The exertion in DH is not just a function of time, but is also influenced by constant changes in direction, variations in loading through corners and impacts with obstacles. The RLd may also provide a more accurate and valid index of the physiological stresses experienced by the rider than HR measures alone, whilst RLd_{Acc} provides an indication of the exertion over the duration of the activity. The results of the present study revealed significant differences in RLd between course types, with the MM course showing lower values. This may be due to fewer impacts with sharp edged obstacles and fewer vertical drops encountered during the MM course. Though the MM course had more jumps, these generally had much smoother, longer landing zones than jumps encountered on the NT course. This potentially may have led to reduced loading upon landing. Additionally, less frequent braking may have been required to negotiate the banked corners of the MM course.

The MM course was ~700 m longer than the NT course, and as such it could be expected that the resulting RLd_{Acc} would be greater for the MM course. However, RLd_{Acc} was not significantly different between courses. Though the NT course was shorter, it was more technically demanding in nature, therefore resulting in RLd_{Acc} values that were comparable to those of the longer, but technically easier MM runs. This may reflect the efficiency of DH bicycles' suspension systems to reduce trail shocks and limit the impact loads transferred to riders. However, anecdotal evidence from riders, coaches and mechanics suggests an increasing belief that DH suspension systems need a stiffer set up than what has been used in previous years to cope with the high speed, high impact nature of modern DH courses. However, such beliefs may be counterintuitive, as this may lead to further impact loads being imposed upon the rider and result in premature fatigue.

When HR's were analysed over the full runs, no significant differences were revealed for either mean or peak HR between course types. This may be the result of several factors. Upper body isometric muscle activity, particularly during non-pedalling phases, may have contributed to the relatively stable HR's throughout the NT runs to maintain bicycle control over the rougher ground of the NT course. Recently, Hurst et al. (2012) reported peak electromyography (sEMG) value ranging between 200 and 300 % of maximal voluntary isometric contraction values for a range of upper body muscles. Smolander et al. (1998) also showed that isometric contractions during a grip strength test resulted in higher HR's when compared to dynamic exercise. Due to the rougher nature of the NT, it is possible that riders were required to grip the handlebars with more force to control the bike during these runs compared to the MM runs. Burr et al. (2012) investigated grip strength following a DH ride and found a significant decrease in pre to post ride grip strength. However, their study was limited in that it did not evaluate the grip dynamics during the runs themselves. In contrast, the more flowing nature of the MM course may have afforded riders more pedalling opportunities, resulting in comparable HR's to the NT course. It would be expected that this is more from aerobic and anaerobic contributions rather than greater isometric contributions during the NT course. This is again supported by Hurst et al. (2012) who reported no significant differences in upper body sEMG activity between NT and MM courses in the same group of riders used in the current study. Sperlich et al. (2012) previously highlighted the need for high aerobic and anaerobic capacities for elite DH riders, and proposed that course design would influence the relative contributions of these systems to performance. Further research is therefore warranted to evaluate the grip forces exerted by riders during different course terrains.

Mean HR in the current study was higher during both course types than those reported for trained amateur DH riders by both Hurst and Atkins (2006) and Burr et al. (2012), but slightly lower than those reported for elite DH riders by Sperlich et al. (2012) during the 2010 German Championship race. The current study distinguishes itself from previous studies in that it assessed the influences of course design, and not only activity profiles. Differences in ambient conditions, or the skill levels of the riders, as alluded to by Sperlich et al. (2012), may also have influenced the results, and partly explain the HR differences between studies. The current findings show that for the cohort of elite riders tested, mean HR, irrespective of course type, was >93 % of peak HR values, whilst the majority of NT run time was spent above 90 % peak HR. This indicates that NT DH riding was performed at very high intensity, echoing the findings of Sperlich et al. (2012). In contrast, the time spent above 90 % peak HR during MM runs was lower than during NT runs. The reduced time spent at high intensity during MM runs, may reflect the smoother nature of this course and reduced effort required to manoeuvre the bicycle. The lower HR values reported by Burr et al. (2012) may reflect the intensity investigated, which would appear to be more recreational as opposed simulated race conditions.

Conclusions and Limitations

The current study supports that DH mountain biking at an elite level can be characterised as high intensity and highlights the influence of course terrain on activity profiles. Further, this study demonstrates that wearable GPS technology can provide a practical and ecologically valid means of monitoring performance profiles in DH mountain biking under varying course conditions.

One of the limitations of this study is however, that riders performed only one run of each DH course. Though three runs on each course had been initially proposed, only one run was possible due to the allocated time on site. Despite this limitation, to the authors' knowledge, the present study is the first to use GPS to investigate activity profiles in mountain biking and more specifically DH. Therefore, this study provides a platform from which future research can be developed. Further research should aim to assess multiple runs per course and monitor activity profiles of DH riders over an entire race season

Practical applications

The current study demonstrates the ability of GPS technology to differentiate between activity profiles when performing DH mountain biking over different course types. The use of GPS would enable riders and coaches to better monitor training and racing loads during DH and subsequently devise more appropriate training schedules. The lightweight, un-intrusive nature of GPS devices means that riders can wear the units without compromising performance. Analysis of GPS and accelerometry data may help inform riders and mechanics of the optimal bike set-up for individual courses, to reduce the loading upon a rider. Such use of GPS could lead to further improvements in performance and reductions in injury.

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